

NASA SP-5930 (01)

THERMAL INSULATION

A COMPILATION



TECHNOLOGY UTILIZATION OFFICE
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
1970
Washington, D.C.

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Foreword

The National Aeronautics and Space Administration and Atomic Energy Commission have established a Technology Utilization Program for the dissemination of information on technological developments which have potential utility outside the aerospace and nuclear communities. By encouraging multiple application of the results of their research and development, NASA and AEC earn for the public an increased return on the investment in aerospace and nuclear research and development programs.

This publication is part of a series intended to provide such technical information. Coverage of thermal insulation technology ranges from innovative concepts to proven insulation materials and applications. Of particular interest are the extensive investigations conducted by aerospace agencies in the development of insulation systems capable of reliable performance despite minimum weight and size constraints. Test results, reflecting both laboratory and field evaluation of material properties and structural capabilities, have direct transfer value to a broad segment of industry.

Additional technical information on individual devices and techniques can be requested by circling the appropriate number on the Reader's Service Card included in this compilation.

Unless otherwise stated, NASA and AEC contemplate no patent action on the Technology described.

We appreciate comment by readers and welcome hearing about the relevance and utility of the information in this compilation.

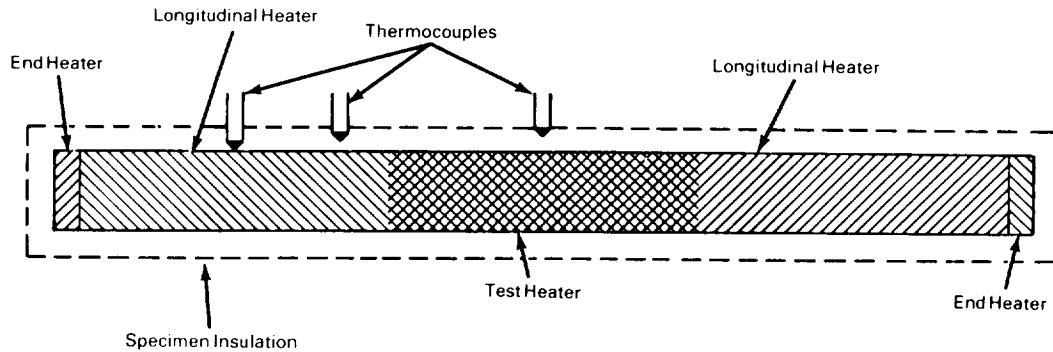
Ronald J. Philips, *Director*
Technology Utilization Office
National Aeronautics and Space Administration

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Section 1. Research and Design

THERMAL CONDUCTIVITY MEASUREMENT OF HIGH PERFORMANCE INSULATION



Thermal conductivity may be measured as a more discrete function at temperature drops of approximately 10 °F in comparison to 200°F levels in previous methods. The measurement is conducted across the insulation to ensure accuracy by minimizing the longitudinal heat losses. A silicone resin-fiberglass tube approximately 3 ft long, 3 in. outside diameter, and a 1/16 in. wall, supports the insulation. Five heaters, wound from 6-mil copper heater wires, are arranged along the support tube. Two "longitudinal heaters" bracket the test heater to simulate the infinite cylinder effect. Two "end heaters" which are 1 in. long, and a 1 ft long "test heater" complete the unit. A separate variable power control for each heater ensures uniform temperatures over the entire cylinder length. After insulation samples are wrapped

around the heater wires, thermocouples are positioned at both inner and outer surfaces of the specimens to monitor their temperatures. Heat flux values are calculated from the measured current and voltage in the test heater. Since the internal and external radii and length of the insulation are known, thermal conductivity is readily calculated by substituting experimental data values into the standard log-mean temperature formula.

Source: E. H. Hyde
Marshall Space Flight Center
and L. D. Russell of
Lockheed Missiles and Space Company
under contract to
Marshall Space Flight Center
(MFS-14088)

Circle 1 on Reader's Service Card.

CRYOGENIC GAS STORAGE SYSTEM THERMAL PROTECTION DESIGN IMPROVEMENT

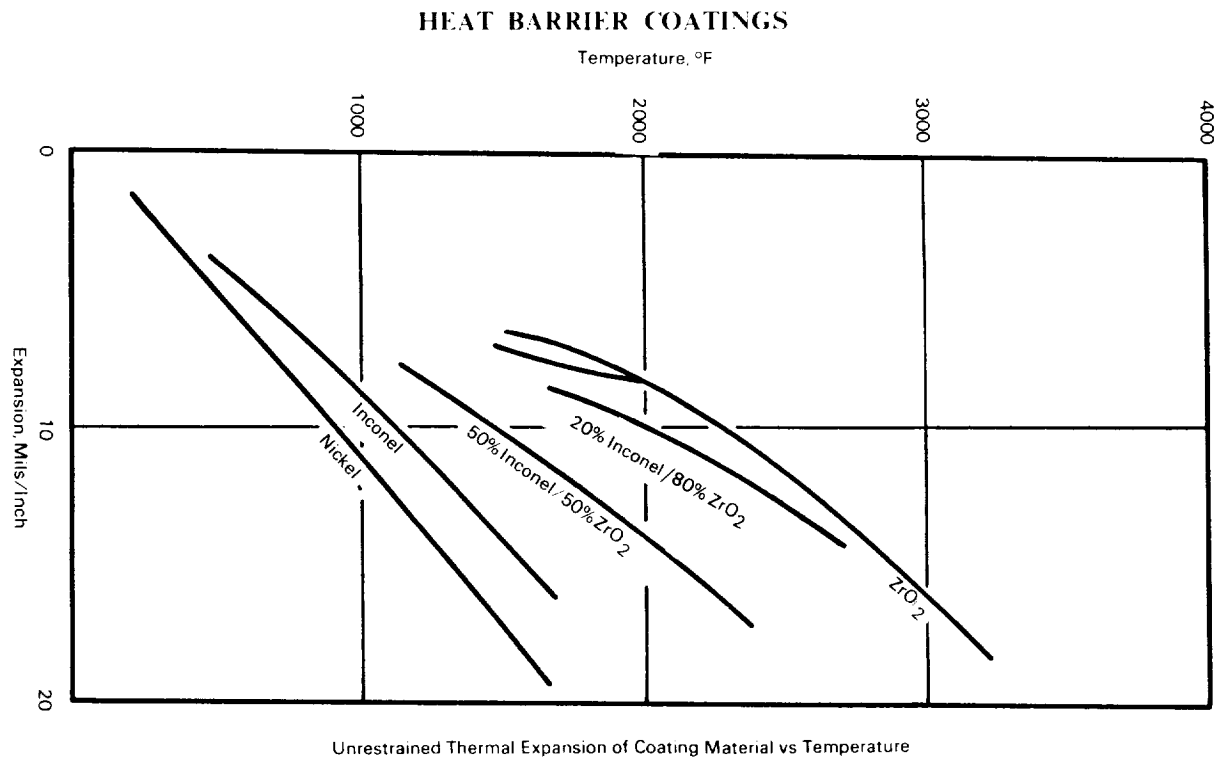
Significant thermal radiation protection is afforded by the addition of a thermal shield within the vacuum annulus in a cryogenic gas storage system. The vapor cooled shield decreases the temperature surrounding the pressure vessels since the vapor carries away considerable heat during

periods of high flowrate. Storage of cryogenic gas is also improved by the application of optical design techniques to multilayer coatings of a gas storage vessel. This additional refinement of selectively applying absorbing, transmitting, or reflective coatings depends upon the thermal

behavior of the system. Since portions of the incident wavelengths are reflected at each of the multiple layers, accurate sizing of the layer thicknesses determines the degree of thermal radiation.

Source: M. L. Davis and
R. K. Allgeier, Jr.
Manned Spacecraft Center
(MSC-12137)

Circle 2 on Reader's Service Card.



Successful development of thermal materials and testing procedures has resulted from extensive investigations of heat barrier coatings by aerospace industries. The initial procedure in designing heat barrier coatings is the establishment of thermal protection requirements, i.e., the thermal resistance of the coating required to reduce the heat flux through the chamber wall (in the case of a rocket engine), and the metal surface temperature below acceptable limits. Often, selection of an optimum thermal resistance value is a compromise between the coating thickness and the thermal protection. Thick coatings are avoided for economic reasons, convenience in coating deposition, and most importantly, to minimize thermal shock. Thermal expansion of arc-plasma

sprayed layers of graded Inconel and zirconia has been investigated during the selection of materials to resist stress buildup at interfaces between graded layers. A simple and inexpensive test to screen coating systems consists of exposing a water-cooled coated sample of a test coating to a controlled arc-plasma jet at the temperatures anticipated during operations. The test is limited, however, by the small area tested and the low shear force of plasma gases.

Source: H. W. Carpenter of
North American Rockwell Corp.
under contract to
Marshall Space Flight Center
(MFS-18618)

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CRYOGENIC INSULATION OF FLEXIBLE LINES

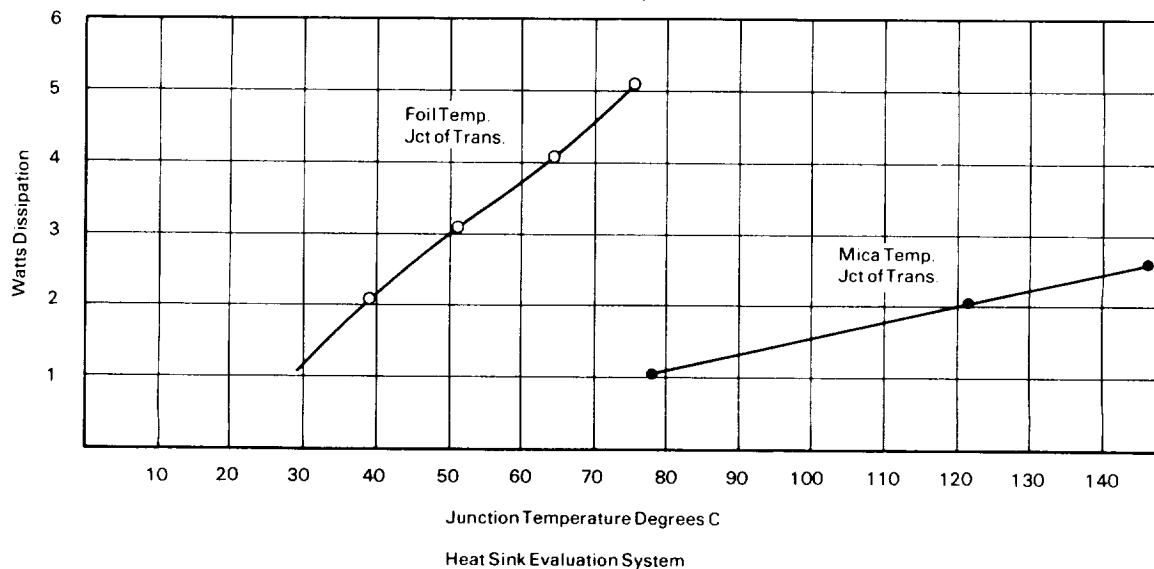
Thermal protection for flexible metal "bellows", expansion joints, and various other liquid hydrogen (LH_2) feed lines is furnished by a combination of insulation materials. Fibrous glass batting is used to supply low thermal conductivity. A fluorocarbon film provides moisture protection and is sealed to control cryopumping of the glass batting during exposure to LH_2 . The final element, a 0.003-in.-thick polyurethane-impregnated nylon cloth, features tear resistance to rough handling often encountered during assembly of ad-

jacent equipment. This insulation has the capability of remaining flexible over a temperature range of $+300^\circ F$ to $-433^\circ F$, and is therefore suitable to insulate flexible surfaces in LH_2 fuel feed lines.

Source: I. Islamoff of
Hayes International Corp.
under contract to
Marshall Space Flight Center
(MFS-13773)

Circle 4 on Reader's Service Card.

HEAT SINK EVALUATION: A CONCEPT



Transistor junction temperatures were used to evaluate the thermal transmission characteristics of indium foil and mica insulation for semiconductor devices. A comparison of the two materials indicated that indium demonstrated superior heat transfer properties. The junction temperature of a power transistor when coupled to a heat sink with indium foil ranged from 30° to $76^\circ C$ over a 1 to 5 watt power input range. The mica coupled transistor indicated a junction tem-

perature of $172^\circ C$ at a 3 watt power input when the test was terminated to avoid exceeding the manufacturer's maximum junction temperature specification of $200^\circ C$. This innovation may be useful in semiconductor component testing and thermal-load control applications.

Source: M. C. Latham
NASA Pasadena Office
(NPO-10843)

Circle 5 on Reader's Service Card.

LOW COST EXTERNAL INSULATION FOR BULKHEADS

Destructive loading in the insulation of large tanks filled with cryogenic liquids is avoided by using a reinforced foam insulation to maintain structural integrity. The insulating procedure starts by bonding a scrim cloth intermittently to the tank wall. A thin coat of foam is then sprayed on the cloth, which penetrates and forms a structural foam layer attached to the wall. Before this coat is completely cured, a second scrim cloth is imbedded over the tacky foam. This process is

repeated as often as necessary to obtain the desired thermal properties. The final cover is an impregnated close weave cloth which coats and seals the structure.

Source: D. Rossello of
McDonnell Douglas Corp.
under contract to
Marshall Space Flight Center
(MFS-12960)

Circle 6 on Reader's Service Card.

REFLECTIVE INSULATOR LAYERS SEPARATED BY BONDED SILICA BEADS

To eliminate separate, bulky nonconductive sheets in multilayer reflective insulation, nonconductive separators have been bonded to the metallic reflective sheets prior to fabrication of the end product. This eliminates the need for separate nonconductive sheets and simplifies the fabrication process. Previously used sheets of fiberglass and similar materials presented fabrication and weight problems.

A layer of small, closely spaced hemispherical beads of relatively pure silica, silicate, or other oxide is applied to the reverse side of each metallic reflecting surface. Spacing and height of the beads are related to reflector thickness. Any desired number of treated reflectors may then be joined by standard methods to form multilayer reflectors tailored to the application. In one application, 15 layers of foil treated with silica beads

have a total thickness of only 0.0075 inch, but are as efficient as 0.875 inch of conventional insulation.

Lithographed aluminum foil is useful for cryogenic applications, while nickel sheets flame-sprayed with aluminum oxide function well at temperatures approaching 2200°F.

Heavy-gauge reflectors may be used in those applications where weight is not a consideration. In weight-sensitive applications, titanium sheets to a thickness of 0.0001 inch may be employed.

Source: N. T. Zuver, Jr. of
Grumman Aerospace Corp.
under contract to
Manned Spacecraft Center
(MSC-00215)

No further documentation is available.

TAPE WOUND CRYOGENIC INSULATION

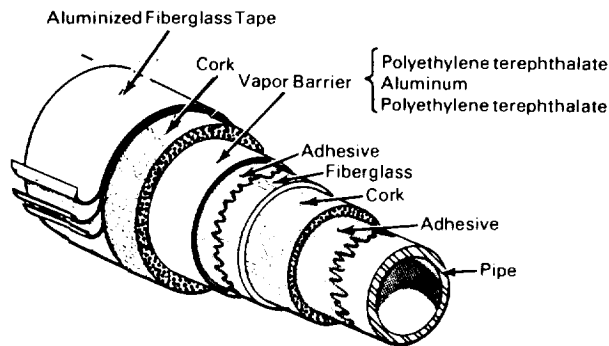
Desirable cryogenic insulation properties, venting characteristics, and high-energy particle absorption qualities are embodied in multilayer insulation systems. These high performance systems feature thin, low conductivity spacers interleaved between tape wound layers of 1/4 mil aluminized polyethylene terephthalate radiation shields. Manufacturers and designers of cryogenic storage tanks, piping, and transportation facilities can benefit from the literature searches and laboratory tests conducted and described in this tech-

nical report. Insulation materials are described in terms of their cryogenic potential (both singly and in combination), supported by graphs and illustrations.

Source: R. Burkley and
J. Stuckey of
Goodyear Aerospace Corp.
under contract to
Marshall Space Flight Center
(MFS-13622)

Circle 7 on Reader's Service Card.

INEXPENSIVE CRYOGENIC INSULATION REPLACES VACUUM JACKET



A capability to withstand extreme temperatures reaching 600° to 700°F in an exposed environment is provided by this newly designed multi-layer sealed insulation system. This insulation system is fabricated from the following commercially available materials: cork board, adhesive, fiberglass tape, aluminum foil-lined fiberglass tape,

and polyethylene terephthalate-aluminum-polyethylene (plastic) sheath. Addition or subtraction of insulation layers increases the system adaptability to varying field requirements. Field service of this insulation system has demonstrated that an 8-in. cryogenic pipe line using 1-in.-thick insulation will have a heat leakage flow rate of approximately 109 Btu/ft²/hr. Although vacuum jacketed piping systems are more efficient than the proposed unit, they are more expensive, require special procurement of factory assembled parts, and are not adaptable to field alterations.

Source: C. E. Fuchs
Westinghouse Astronuclear Laboratory
under contract to
Space Nuclear Propulsion Office
(NUC-10061)

Circle 8 on Reader's Service Card.

STORAGE TIME EXTENSION OF EXISTING CRYOGENICS TANKS

The thermal performance of a cryogenic tank may be improved through the use of a multi-layered insulation blanket of aluminized plastic (polyethylene terephthalate), fiberglass tension support rods, and stainless steel fill and vent lines. Wrapping the vent line around the tank before the addition of superinsulation provides an improvement of storage time, but a tension member tank support addition is required for longer storage periods.

Research has indicated that cryogenic storage is superior to ambient storage for short periods (up to 1300 hours in Apollo X tanks), but for long-

er periods, storage at ambient temperature and high pressure is more economical. To obtain these results, however, it is necessary to maintain environmental temperatures ranging from 40° to 90°F in the tankage storage area. Higher temperature values affect the heat-leak rate and change the density of the stored gas.

Source: G. Knowles of
Grumman Aerospace Corp.
under contract to
Manned Spacecraft Center
(MSC-11818)

Circle 9 on Reader's Service Card.

MANUFACTURING TECHNIQUES FOR APPLICATION OF CRYOGENIC INSULATION

Detailed descriptions of preliminary design, structural analysis of critical members, and thermal analysis are given in a manufacturing procedure developed for a multilayer insulated torus tank. Insulation materials were considered on the basis of their fabrication and handling charac-

teristics as well as thermal and physical properties. Research was conducted on silk or nylon netting, rigid polyurethane foam, and sliced 3/4-inch polyethylene terephthalate honeycomb alternately interleaved with reflective shields of aluminized polyethylene terephthalate.

A comprehensive manufacturing plan was prepared, for the insulation system components of a 200-inch-diameter torus tank which contained the major tooling requirements and their application. Numerous illustrations and graphic presentations add to the value of this document.

Source: C. L. Lofgren and
D. C. Gieseck of
The Boeing Company
under contract to
Marshall Space Flight Center
(MFS-14557)

Circle 10 on Reader's Service Card.

A STUDY OF THERMAL CONDUCTIVITY

The relationship between "apparent" thermal conductivity and temperatures for various high performance multilayer insulation materials ranging from -50° to $+200^{\circ}\text{F}$ is documented in this experimental study. A cylindrical calorimeter was developed to measure the temperature drop after a steady state heat flux was transmitted through a one-inch-thick specimen of insulation. Insulation materials tested included: 1/4 mil single and double aluminized plastic (polyethylene terephthalate), fiberglass needles, 30-mil polyurethane foam, and a rigid urethane foam. Conclusions

reached from this research are presented in both tabular and graphic format for individuals interested in insulation technology.

Source: D. V. Hale,
W. H. Sims, and
J. H. Lane of
Lockheed Missiles and Space Company
under contract to
Marshall Space Flight Center
(MFS-14351)

Circle 11 on Reader's Service Card.

CRYOGENIC INSULATION RESEARCH FOR AEROSPACE VEHICLES

The aerospace requirements for light but extremely reliable cryogenic insulation systems focused research on high vacuum jackets; powders under atmospheric pressure or evacuated states; foams which were rigid or formed in place; and structures including honeycomb, and multilayer (with or without vacuum jacket). Insulation systems were sought which would be inexpensive, rugged, easily repairable and convenient to handle. Materials and constructed forms were subjected to internal and external insulation trials in

laboratory tests and scale models. Results of these investigations are documented in both graphic and tabular form for easy transference to industrial applications.

Source: I. Islamoff of
Hayes International Corp.
under contract to
Marshall Space Flight Center
(MFS-13773)

Circle 12 on Reader's Service Card.

CRYOGENIC INSULATION DEVELOPMENT

Evaluation of several insulation systems is based on scale model performance in test environments subjected to rapid pressure drops, acceleration, low temperatures, and acoustic noise. Con-

sideration was given to the thermal and structural performance of multilayer insulation systems during ground and space flight operation. Rigorous tests were conducted on a shingle-type crinkled

aluminized plastic (polyethylene terephthalate) insulation and also on a second type consisting of 0.030-inch foam and aluminized plastic (polyethylene terephthalate). Indications of insulation failures were evaluated and corrective measures developed to provide the requisite reliability in the final tests.

Although standards for space flight are necessarily higher than for the majority of industrial applications, the documented results of these

space applications should provide useful background information for makers of thermal insulation products.

Source: R. C. Gethy of
General Dynamics/Astronautics Corp.
under contract to
Marshall Space Flight Center
(MFS-14740)

Circle 13 on Reader's Service Card.

MULTI-LAMINAR INSULATION

Reflective properties required for thermal insulation are provided by a fiberglass fabric with one side fortified by a layer of vacuum deposited metal. The resultant material adapts to complex surfaces and curvatures, yet is separable for variable spacing. The porosity of this reinforced fabric permits easy evacuation of trapped gas molecules in contrast to the commonly-used aluminum foil. Additionally, the material has performed satisfactorily under extreme evacuation pressures of ap-

proximately 10^{-5} torr. Based upon these desirable features, this material should interest chemical, air conditioning, and insulation designers.

Source: L. Isenburg and
M. B. Hammond of
North American Rockwell Corp.
under contract to
Marshall Space Flight Center
(MFS-14831)

Circle 14 on Reader's Service Card.

Section 2. Insulation Systems and Components

WIRE COIL USED TO FORM IRREGULAR SHAPE PURGE CHANNELS

Inexpensive formation of irregular purge channels around a cryogenic insulated container may be accomplished through the use of an encased wire coil. This procedure reduces the procurement of preformed parts produced by costly die and tooling techniques. Chilledown requirements, prior to filling a cryogenic tank and leak detection searches after filling, require purge channels of several locations between the insulation and the tank wall. Formation of these channels is especially difficult around the large fluid ducts leading to the tank which normally requires thick insulation for super-cold liquids. Coils of

wire (approximately 0.4-in.-inner diameter) are covered with a resin impregnated fabric, and placed along contours where purge channels are required to form a conduit for gas flow. Gas at low pressure is then introduced for cooling and detection of possible tank leakage.

Source: C. D. Crouse of
North American Rockwell Corp.
under contract to
Marshall Space Flight Center
(MFS-16381)

Circle 15 on Reader's Service Card.

PROTECTIVE COATING WITHSTANDS HIGH TEMPERATURES IN OXIDIZING ATMOSPHERE

A plasma-arc sprayed mixture of hafnium oxide and zirconium diboride provides a protective coating that will withstand high temperatures in an oxygen-rich atmosphere. Used on a thermocouple, it does not degrade response time and it protects the base material a sufficiently long time for proper temperature measurement.

A mixture of hafnium oxide and zirconium diboride in a 1:1 ratio based on the atomic weight of the metal is prepared with a particle size distribution of between approximately -125 and +325 mesh and an average particle size of about 200 mesh. The powdered mixture is dispersed in an inert gas that passes through an electrical discharge arc at a typical temperature of 3000° to 5000°K. The resultant plasma jet is a hot, fluid, gaseous stream and is directed toward the substrate to be coated, this being surrounded by a cooling atmosphere of an inert gas such as argon. The plasma jet stream condenses on the cooled

substrate surface to provide the desired protective coating.

A coating on the order of 0.002 to 0.050 inch on a homogeneous tungsten thermocouple surface gave good protection, did not flake or crack on subsequent cooling and reheating, and did not degrade the thermocouple response time.

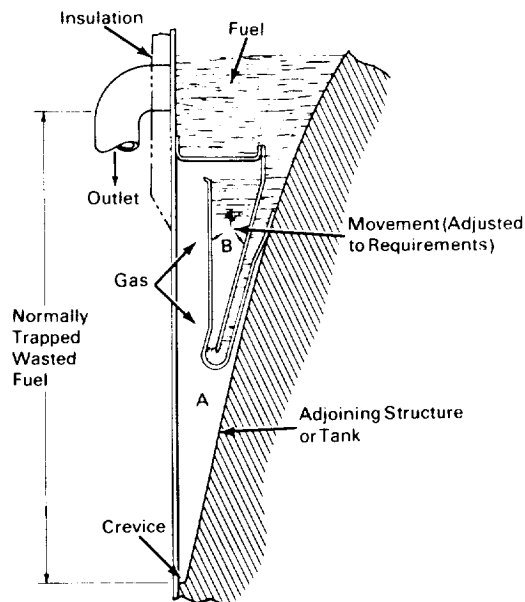
This coating withstood a temperature of 4700°F for 5 minutes with no apparent damage to the substrate. Exposure to 3700°F for 30 minutes gave the same result.

Patent status:

Title to this invention has been waived under the provisions of the National Aeronautics and Space Act (42 U.S.C. 2457 (f)), to Fenwal Incorporated, Ashland, Massachusetts.

Source: Marshall Space Flight Center
(MFS-00529)

FLEXIBLE GAS TRAP INSULATOR FOR CRYOGENIC TANKS



Inexpensive cryogenic tank insulation may be provided by a gas trap utilizing hydrogen (H_2). As shown in the diagram, Cavity "A" is insulated

in the bolting ring area to minimize heat transfer from liquid oxygen (LOX) to hydrogen. This process employs liquid hydrogen (LH_2) gasification. LH_2 flows to the bottom of Cavity "B", then rises to the top of the trap. As the liquid spills over the edge it drops to the warm surface at the bottom of the crevice. At this point it changes to a gas and extends a pressure downward from the top of the trap. This pressure balances the LH_2 heat, keeps Cavity "A" empty to retard heat flow, and further reduces the unstable LH_2 volume below the outflow lines.

This innovation saves the fuel ordinarily lost in small insulated crevices, provides a means of retrieving loose items accidentally dropped into the tank, and can also be made movable to fit a mobile mechanism within or adjoining a cryogenic tank.

Source: R. C. Englehart of
North American Rockwell Corp.
under contract to
Marshall Space Flight Center
(MFS-13340)

Circle 16 on Reader's Service Card.

REFRACTORY COATING PROTECTS INTRICATE GRAPHITE ELEMENTS FROM HIGH TEMPERATURE HYDROGEN

In one application of an induction furnace, graphite heater elements must operate at temperatures as high as 3500°F for at least 1/2 hour in a hydrogen atmosphere. Uncoated graphite elements are damaged at temperatures above approximately 2500°F. Intricate shape of the elements prevented application of a refractory coating by vapor deposition. A composition containing powdered tungsten has been developed and can be painted on the graphite elements and heat treated to form a tightly adherent 3-mil-thick refractory coating.

The graphite heater elements are painted with a thin coat of a mixture containing the following ingredients, in parts by weight: 10 to 30 tungsten powder (325 mesh), 2 carbon black, 9 commercially available phenol-formaldehyde varnish or paint, and 0.4 maleic anhydride. The coated parts are then cured in air over the following time-temperature cycle: from room temperature to 100°C in 1 hour, at 100°C for 1/2 hour, and from 100° to 250°C in 3 hours at the rate of 50°C per hour. Following the curing cycle, the coated heater elements are baked in a 10^{-2} torr vacuum while the temperature is raised from room temperature to 850°C at the rate of 50°C per hour. The coated

parts are then connected as electrical resistive loads in an atmosphere of pure methane and supplied for 2 minutes with 216 watts of power per square inch of exposed area. This treatment produces a carbonaceous crust, which is brushed off after the power is turned off. The process is completed by placing the parts in an atmosphere consisting of hydrogen and methane (5% by volume) at 200 psia and applying the electrical power at a rate increasing steadily from 226 watts to 344 watts per square inch in one hour.

A coating of 3 mils thickness heated to 4000°F has withstood a hydrogen atmosphere for half an hour, with no apparent degradation. This process, which is simpler and less costly than the vapor deposition process, can be used to protect graphite parts for induction furnaces. It may also have application in semiconductor technology.

Source: C. E. Vogel, J. R. Ferris, R. L. Patterson, and R. J. Steffen of Westinghouse Astronuclear Laboratory under contract to Space Nuclear Propulsion Office (NUC-00027)

Circle 17 on Reader's Service Card.

FLEXIBLE PROTECTIVE COATINGS MADE FROM SILICON-NITROGEN MATERIALS

Two substances have been successfully used as protective coatings that withstand elevated temperatures for long periods while retaining their flexibility. They are: a polymer obtained as a byproduct in the preparation of hexaphenylcyclotrisilazane and a polymer obtained by heating bis(methylamino)-diphenylsilane.

The first substance is produced by treating diphenyldichlorosilane with ammonia and evaporating the mother liquors after the crystalline hexaphenylcyclotrisilazane has been separated by filtering. The resinous byproduct forms the protective coating after curing briefly at 300°C.

The second substance is produced by heating bis(methylamino)diphenylsilane at 315° to 320°C for two hours and removing the resultant crystals by centrifugation. The remaining liquid byproduct forms the protective coating after brief heating at elevated temperatures.

Aluminum panels treated with the first coating and cured for one hour at 300°C were visibly unaffected by one hour in boiling water. Placed in a 19% hydrochloric acid solution, the coated areas were still unaffected when uncoated areas were black and deeply etched. The second coating, on stainless steel, did not crack when the panel was bent repeatedly after having been heated at 500°C for an hour.

Patent status:

Title to this invention has been waived under the provisions of the National Aeronautics and Space Act (42 U.S.C. 2457 (f)), to the Southern Research Institute, 2000 Ninth Avenue South, Birmingham, Alabama.

Source: Marshall Space Flight Center (MFS-00528)

COATING PERMITS USE OF STRAIN GAGE IN WATER AND LIQUID HYDROGEN

Strain gage measurements had to be made in water and subsequently in liquid hydrogen. Previously, a separate strain gage was used for each measurement because no single strain gage installation could be used successfully in both environments. Now, a new approach has resulted in a single strain gage to make both measurements sequentially. The foil strain gage used is bonded with a modified heat-curing epoxy cement and covered with a 3-layer coating of commercially available protective materials.

The surface on which the gage is to be mounted is first subjected to a thorough cleaning and abrading treatment. A drop of distilled water will flow freely on a properly prepared surface.

A 1-mil precoat of a modified heat-curing epoxy resin is applied to the prepared surface and allowed to dry for 4 hours. A 1-mil coat of this resin is applied over the precoat, and the gage and tabs are positioned on the coated surface. The installation is then cured for 4 hours at 225°F under 5 psi clamping pressure. Leads from insulated wires are soldered to the tabs. A small dab of the

epoxy resin is used to bond the lead wires to the test specimen.

A 1-mil coat of a flexible nitrile rubber is brushed over the entire gage and tab area and over the lead wires. This coat is allowed to dry for 15 minutes. A 1-mil coat of a quick-drying resin is applied over the same area and allowed to air-dry for 15 minutes. The last step in the installation procedure is to apply a thin coat of a silicone waterproofing lacquer over the air-dried resin.

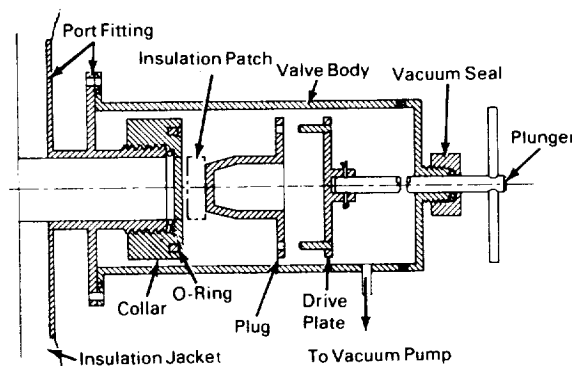
When the gage installation is immersed in liquid hydrogen, the outer silicone lacquer protective layer may develop cracks, which will destroy its waterproofing characteristics. Therefore, when the gage is to be used for strain measurements in water and in liquid hydrogen, the measurements in water must be made first.

Source: B. B. Berven of
North American Rockwell Corp.
under contract to
Marshall Space Flight Center
(MFS-00594)

Circle 18 on Reader's Service Card.

HAND-OPERATED PLUG INSERTION VALVE

Evacuation and sealing of insulation systems are expedited by a light, hand-operated plug insertion valve which is easily demountable. A port fitting is bonded to the insulation jacket during fabrication of the tank. A valve body collar with an internal O-ring is then assembled to the port fitting. The insulation jacket is evacuated to the desired pressure level and the port is sealed by pushing on the valve plunger. The drive plate pins engage holes in the plug and collar (through the plug flange). When the plunger is twisted, the plug-to-collar interface is tightened which, in turn, compresses the O-ring making a vacuum tight connection. After the drive plate is withdrawn, the valve body with associated plumbing is removed from the insulation jacket port fitting. Since this port fitting and plug weigh 1/7 as much as a conventional vacuum valve and the plug can be fitted with a patch of insulation as a barrier to radiation heat transfer, the innovation should interest designers of insulation systems.



Source: A. Roney of
Hayes International Corp.
under contract to
Marshall Space Flight Center and
R. G. Jones
Marshall Space Flight Center
(MFS-12019)

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